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V. *A Description of a new Construction of Eye-glasses for such Telescopes as may be applied to Mathematical Instruments.*
By Mr. Ramsden ; communicated by Sir Joseph Banks, Bart.
P. R. S.

Read December 19, 1782,

TO correct the errors in eye-glasses, arising from their spherical figure, and also from the different refrangibility of light, it has been held absolutely necessary to have two, placed in such manner, that the image formed by the object-glass of the telescope should be between them; but in those telescopes that are applied to mathematical instruments, the interference of the first eye-glass before the image is formed is productive of many bad consequences; should that eye-glass have the least shake or motion whatever, it totally alters the adjustment of the instrument; and the diminishing also of the image by this position, obliging us to shorten the focus of the nearer eye-glass, the wires in the focus of the telescope are thereby considerably more magnified than they would have been with the same power, had both the eye-glasses been put between the image and the eye.

Many defects in the micrometer with moveable wires are caused by the construction of the eye glasses of the telescope to which it is applied. If only one eye-glass is used, the field is so contracted, that it is impossible to measure the diameter of the sun or moon with precision, if the telescope magnifies above 30 times ;

times; and if, to enlarge the field, we use the present construction of two eye-glasses, the consequence is yet worse; because equal spaces between the wires will not then correspond to equal spaces on the objects it represents, as those conversant in the theory of optics well know; and this inequality depending on the form, position, and refractive power of the first eye-glass, it will be impossible to have data sufficiently exact to allow for that error.

Those who were sensible of this defect have thought to correct it by the application of an achromatic eye-glass, on the principle of that kind of object-glass, not supposing it possible to correct the aberrations from the different refrangibility of light, and also from the spherical figure of the lenses by any other means than combining a concave lens with the convex ones; but the violent and contrary refractions from the necessary large size of the lenses in proportion to their focal lengths, not only occasioned great loss of light, but rendered it impossible to correct the spherical aberration so as to obtain an angle of vision much larger than could be had by a single eye-glass: yet, however absurd it may have appeared to attempt correcting both aberrations, when the lenses are both convex, and are on the near side of the wires, the following observations will shew the practicability of it, and may throw some light on the theory of eye-glasses which seems hitherto not well understood.

Sir ISAAC NEWTON has shewn in his *Lectiones Opticæ*, in that section *De Phænomenis lucis per prisma in Oculum transmissæ*, that the appearance of colours on the edges of objects when viewed through a prism depends on the proportion of the distance between the prism and the object, compared with that between the prism and the eye, that is to say, the nearer the object is brought

brought to the prism, the less will be the border of colours on the contours of the object.

To apply this to practice I placed a plano convex lens *a* (*vide* fig. 1.) with its plane side near an object, or an image *IN* formed by the object-glass of a telescope, and thus magnified the image which, from the position of the lens, was sensibly free from colour; but the respective foci of a lens so placed being very near each other, and on the same side, the emergent pencils diverge on the eye, and give indistinct vision: this was remedied by placing a second lens *k* a little within the focus of the former, the combined foci of the two lenses being in the place of the image, the rays were thereby made to fall parallel on the eye, and to shew the object *IN* distinctly. If, by putting the lens *a* very near the image, any imperfection in it becomes too visible, that distance may be considerably increased, without producing any bad effect; for theory, as well as experiment, shews, that a small aberration from the different refrangibility of light is of little consequence compared with the same quantity of aberration caused by the spherical figure of the lenses, but even that colouring may be corrected in the nearer eye-glasses: for let a ray (fig. 2.) from an object *o*, by passing through a lens *B*, be separated into colours, *ac* being the direction of the violet rays, and *at* that of the red; if another lens be put at *c*, the violet rays passing through its center will suffer no refraction, while those of the red, passing at some distance from thence are refracted, and the emergent red and violet will be parallel, when the mean refracting angle of the lenses at the incidence of each pencil are to one another inversely as the diameters of those pencils.

If we attend to this position of the eye-glasses, it will be found equally advantageous for obviating the spherical aberration
of

of an oblique pencil as that from colour. In both, where there is a necessity for having a large portion of a sphere, we have only to make the pencil on such lens as small as possible, and we may regulate the direction of the rays in each pencil at pleasure when they approach the axis of the telescope.

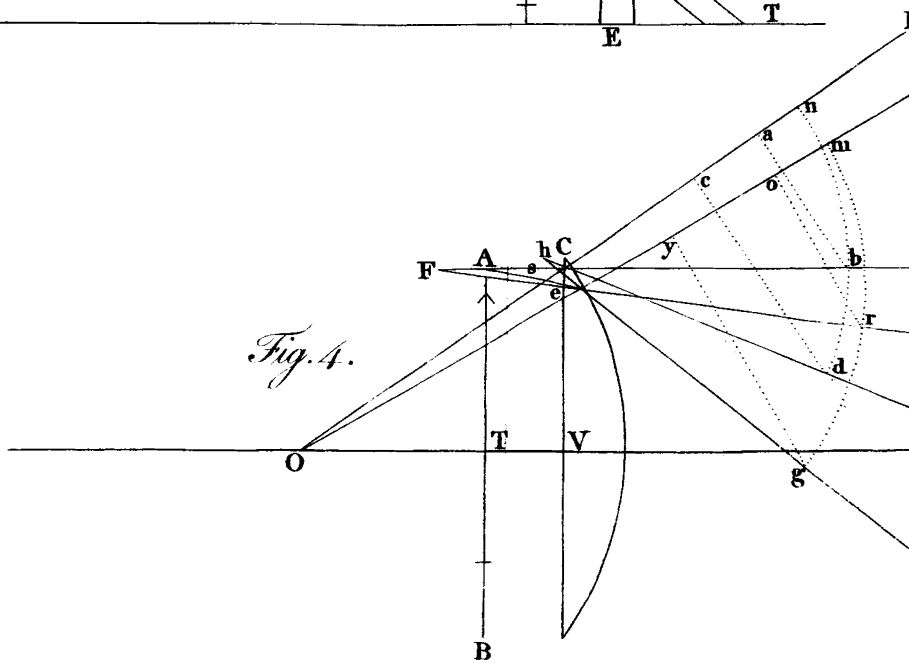
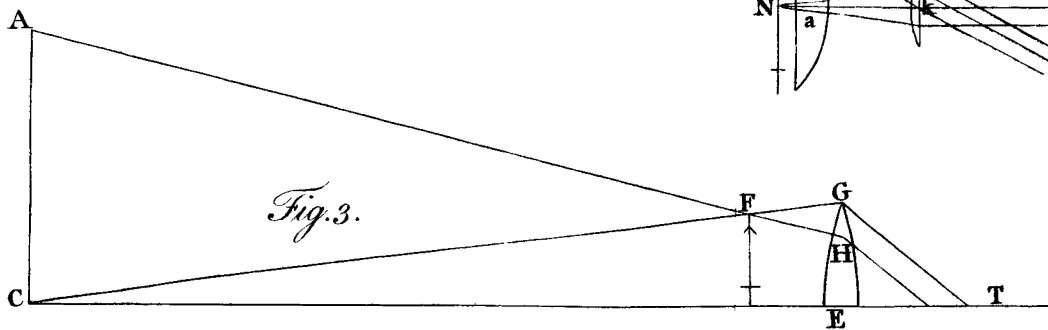
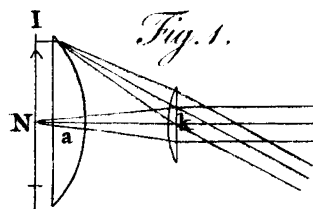
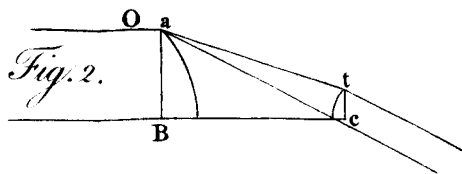
To illustrate this, let us compare the effect of the spherical aberration of a lens on an oblique pencil in this position with that produced by the same lens, placed as usual at its focal distance from the image. Let AC, fig. 3. represent the semi-object-glass of a telescope, CT its axis, E an eye-glass, and F the common focus of both the object-glass and eye-glass. Let AFC be an oblique pencil of homogeneous rays, G and H the points where the axis and the extreme rays pass through the eye glass: the aberration of this pencil from the spherical figure of the lens E will be $EG^3 - EH^3$; but as the lens approaches towards F, EG and GH, becoming equal, this cause of aberration vanishes accordingly. The effects of the lens *k* will be altogether insensible from the smallness of its aperture; or it might be corrected in the figure of the object-glass, by making its aberration negative as much as this is affirmative.

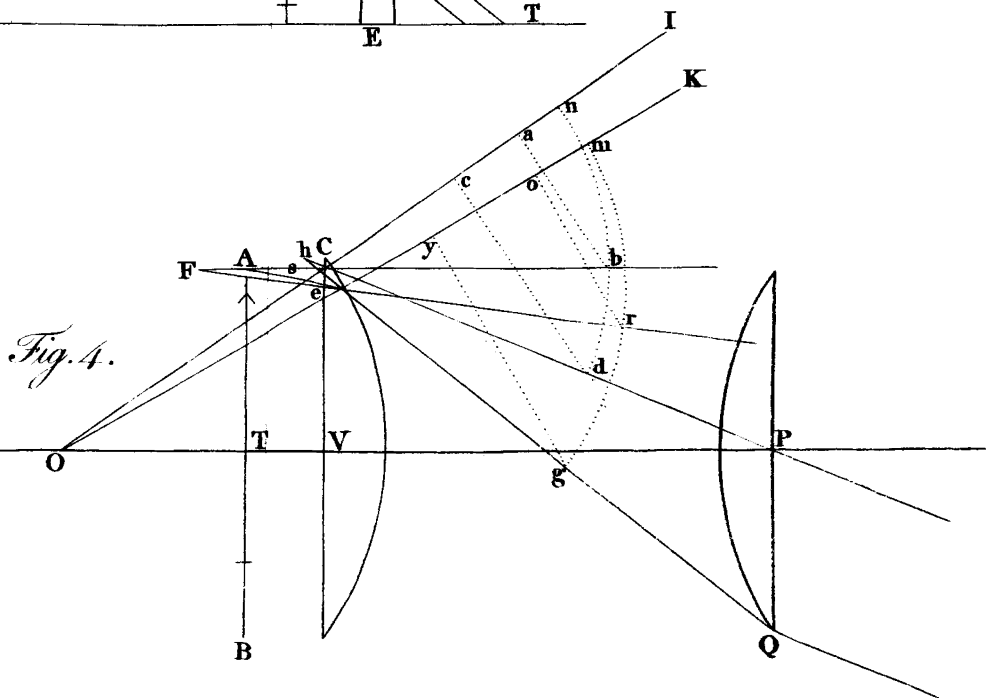
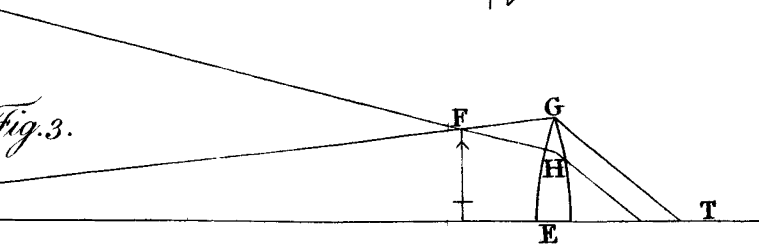
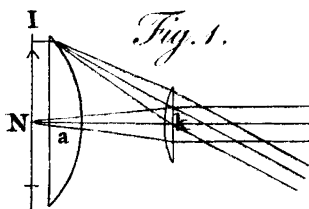
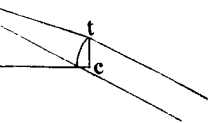
It has been usual to consider that form and position of the eye-glasses best that would make the pencils from every part of the field intersect each other in the axis of the telescope at the place of the eye; but this will be found of little consequence, seeing the diameter of a pencil here is generally much less than the pupil, nothing more is requisite than that the eye may take in the pencils from the different parts of the field at the same time: but the field of a telescope will be most perfect when the construction of the eye-glasses is such, that the focus of an extreme and of central pencil are at the same distance

from the eye. The disposition above described will be found conformable to that idea.

Let AB (fig. 4.) represent an image formed by the object-glass of a telescope, V the first eye-glass, as already described, with its plane side towards the image; let AC be the axis of a pencil of rays incident on the first surface of the lens V , and Ae an extreme ray of the same pencil. Take CF to CA as the sine of incidence out of air into glass is to the sine of refraction, and F will be the focus of this pencil after passing through the first surface of the lens V . From the point F draw the angle CFe , the incident pencil on the second surface of this lens, continue the lines FC and Fe to b and r respectively, and draw the perpendiculars OI and OK on the point C , describe the arc nd , and making cd to ab , as the sine of refraction out of glass into air is to the sine of incidence, draw cd continued till it cuts the axis in P . In like manner, on a center e describe the arc mg , and making yg to or as the sine of the angle of refraction is to that of incidence, draw the line egQ ; continue it and the line Cd backward till they meet each other in h , and it will be the focus of the emergent pencil from the second surface of the lens V . On the axis CF set off the distance Cds equal to Ch , and draw es and Ce . Now it is evident from the figure, that the focus of the emergent pencil will be nearer to C than the object itself, in the proportion the angle Cse exceeds the angle CAe .

Thus, from the great angle of incidence of the oblique pencil on the second surface of the lens, the focus of the emergent pencil is brought nearer to P the second eye-glass, while that of the principal pencil remains the same, or very nearly so; and the image will become more distinct towards the edge of the field the nearer Pb and PT approach to equality.





To give a proper demonstration and theorem for the exact form of the first lens, according to its distance from the image, would require more leisure than is consistent with the situation of one not very conversant with mathematics. That distance, in proportion to the focal length of the lens, so that any unavoidable defect in it may become invisible, must be determined by experiment. If any variation be made in the form of this lens, it will be better to make the plane side rather a little convex than concave. By the latter the image would be distorted by the too great obliquity of the rays near the extremity of the lens.

Thus we have a system of eye-glasses which may be taken out of the telescope, in order to wipe them at pleasure. Or the magnifying power of the telescope may be varied without affecting the line of collimation, or in any manner altering the adjustment of the instrument to which such telescopes may be applied with many other advantages. In the present improved state of telescopes too, the disagreeable appearance of the wires from the great power of the eye-glasses is in a great degree remedied. The same principle may be usefully employed in many other cases. What is herein contained is only to be considered as an explanation of this very useful construction, and which is given in hopes that some person of more abilities in the science of optics will favour us with a general theorem, in order that its application may be more universal.